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**Variability of Prediction of Maximal  
Oxygen Consumption on the Cycle  
Ergometer Using Standard Equations**

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Linda H. Barrows

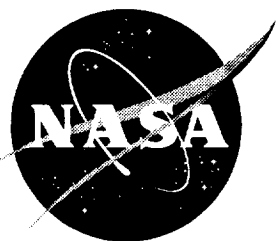
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Michael C. Greenisen

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National Aeronautics  
and Space Administration

**Scientific and Technical  
Information Branch**



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## INTRODUCTION

Several current investigations within the Exercise Countermeasures Project (ECP) at the NASA Johnson Space Center have focused on the assessment of maximum oxygen consumption ( $\dot{V}O_{2\max}$ ) within the Astronaut Corps pre- and postspace flight. Investigations during the Apollo era suggested that there was a significant decrease in postflight  $\dot{V}O_{2\max}$  when compared to preflight values [2, 8], and current studies have documented that this trend continues in the Space Shuttle era [10]. Current studies use protocols, which continue until volitional fatigue, to determine  $\dot{V}O_{2\max}$ , but there is an expressed desire to use submaximal testing on landing day as it would be less physiologically stressful to the crewmembers. Cycle ergometer, rather than treadmill, testing has been proposed as it would provide a stable base from which ancillary measures, including blood pressure and cardiac output, could be taken and subjects would be prone to less neurovestibular and/or orthostatic distress.

It is generally accepted that  $\dot{V}O_{2\max}$  can be predicted from submaximal measures taken during graded-exercise tests on the cycle ergometer with respect to populations [9]. These findings have been confirmed in our own laboratory with subjects cycling at both 50 [4] and 75 [7] revolutions per minute (r/min). However, previous work has not examined the effect of day-to-day variations in the physiologic responses that might alter these predictions for individuals. Stability of individual submaximal data over serial tests is important so that predicted changes in  $\dot{V}O_{2\max}$  are reflective of actual  $\dot{V}O_{2\max}$  changes. Therefore, the purpose of this investigation was to determine which of the accepted equations to predict  $\dot{V}O_{2\max}$  would be less affected by normal daily physiologic variations.

## METHODS

Subjects for this investigation were selected from an existing subject pool based upon their previous experience in prior investigations (two or more) using  $\dot{V}O_{2\max}$  testing on the cycle ergometer. Subjects (n=14) completed two graded-exercise tests on a cycle ergometer to volitional fatigue. Exercise tests were conducted at least 48 hours apart to minimize residual fatigue effects with no more than 2 weeks separating the tests. Testing was conducted at approximately the same time of day for each subject. Subjects were requested to refrain from food and caffeine on the day of testing and to report to the laboratory well-hydrated. Exercise and alcohol consumption were discouraged on the day before each test. Subject characteristics and mean responses to exercise tests are displayed in Table 1.

**Table 1.** *Subject characteristics (10 males, 4 females) (Mean  $\pm$ SD)*

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Age (years)	Weight (kg)	Height (cm)
31.9 $\pm$ 5.2	78.8 $\pm$ 16.6	173.8 $\pm$ 7.7

---

Audio cue (metronome), visual cue (r/min display), and verbal encouragement were given so that subjects pedaled at a constant cadence of 75 r/min. Workloads were increased in 50-Watt increments every 3 minutes until volitional fatigue or until the desired cadence could not be maintained by the subjects. Subjects were strongly encouraged to give a maximal effort.

Heart rate was monitored by a three-lead electrocardiogram configuration and recorded by a Quinton Q5000 Stress Monitoring System. These data were collected and reported at 30-second intervals. Maximal heart rate (MHR) was defined as the highest attained heart rate over a 30-second interval for the exercise testing session.

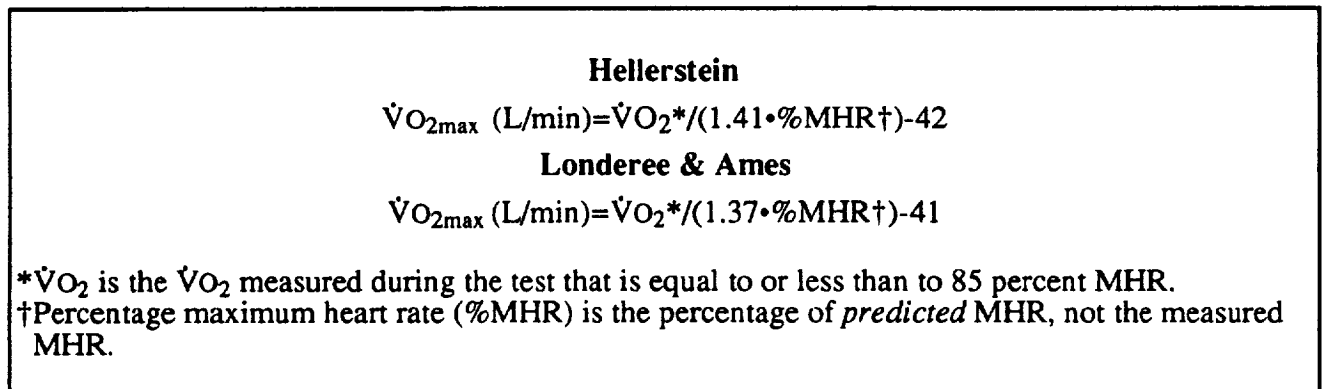
$\dot{V}O_2$  was measured while subjects breathed through a one-way valve. Expired gas was collected and analyzed by a Quinton Q-Plex™ Metabolic Gas Analysis System (Quinton Industries, Seattle, WA) interfaced with a mass spectrometer (Model 1100, Marquette Electronics, Inc., Milwaukee, WI). Expired volumes were measured by the Q-Plex™ and expired gas fractions were determined by mass spectrometry. Measurements were made continuously and reported as an average of 30-second intervals.  $\dot{V}O_{2max}$  was identified as the highest of the 30-second averages attained during the test.

Two standard equations (i.e., 220-age and 205-[0.5•age]) were used to predict MHR (Table 2).

**Table 2.** *Maximal heart rate (b/min) (Mean ±SE)*

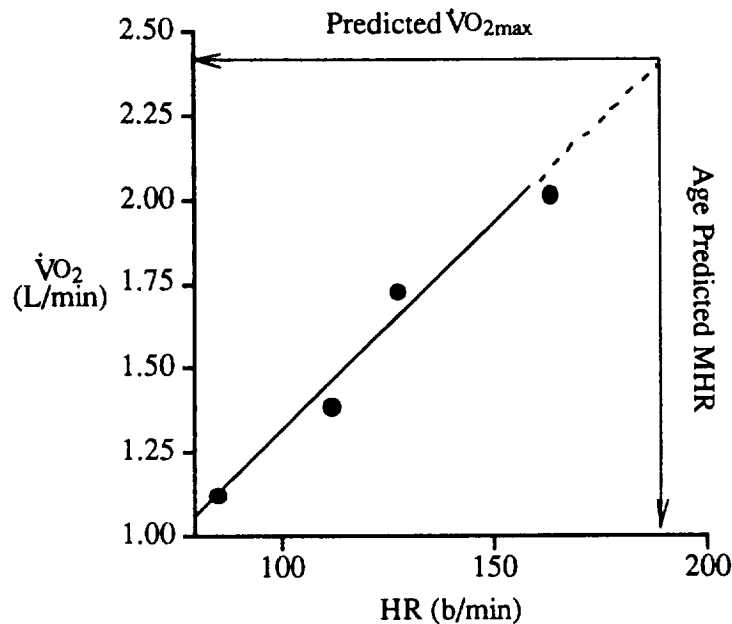
Test #1	Actual Test #2	Estimate 220-Age	Estimate 205-(0.5•Age)
186.0 ±2.0	184.8 ±2.0	188.1 ±1.2	189.0 ±0.6

Using the predicted MHR, three methods (i.e., linear extrapolation [1, 6], Hellerstein single-point [3], and Londeree single-point [5]) (Figures 1 and 2), were used to predict  $\dot{V}O_{2max}$ . The graph in Figure 2 is constructed using the heart rate and  $\dot{V}O_2$  data from the graded exercise test. From this, a regression equation describing the line of best fit is developed. Age predicted MHR is then used in the regression equation to predict  $\dot{V}O_{2max}$ .



**Figure 1.** *Single-point methods*





**Figure 2.** Example of linear extrapolation method

Data points used in the prediction of  $\dot{V}O_{2\max}$  were selected so as not to exceed 85 percent of predicted MHR for each of the two graded-exercise tests. These  $\dot{V}O_{2\max}$  prediction values and the differences are presented separately for each of the MHR prediction methods (Tables 3 and 4).

**Table 3.**  $\dot{V}O_{2\max}$  (L/min) estimates using  $MHR=220-age$  (Mean  $\pm$ SE)

	<u>Actual</u>	<u>Linear Ext.</u>	<u>Hellerstein</u>	<u>Londeree</u>
Test #1	3.53 $\pm$ 0.15	3.27 $\pm$ 0.24	3.28 $\pm$ 0.24	3.39 $\pm$ 0.24
Test #2	3.47 $\pm$ 0.16	3.34 $\pm$ 0.22	3.29 $\pm$ 0.24	3.40 $\pm$ 0.24
Difference	-0.06 $\pm$ 0.06	0.07 $\pm$ 0.08	0.01 $\pm$ 0.02	0.01 $\pm$ 0.02
SEE		0.40	0.28	0.29

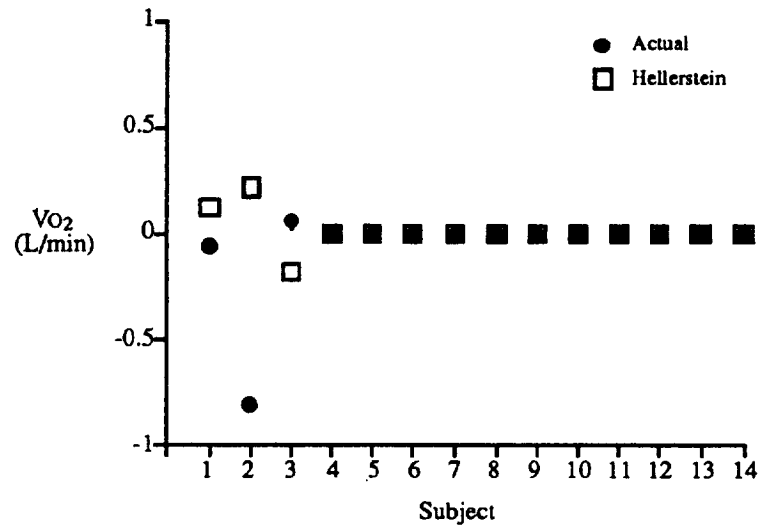
**Table 4.**  $\dot{V}O_{2\max}$  (L/min) estimates using  $MHR=205-(0.5 \cdot age)$  (Mean  $\pm$ SE)

	<u>Actual</u>	<u>Linear Ext.</u>	<u>Hellerstein</u>	<u>Londeree</u>
Test #1	3.53 $\pm$ 0.15	3.30 $\pm$ 0.23	3.30 $\pm$ 0.23	3.41 $\pm$ 0.24
Test #2	3.47 $\pm$ 0.16	3.37 $\pm$ 0.22	3.32 $\pm$ 0.23	3.42 $\pm$ 0.24
Difference	-0.06 $\pm$ 0.06	0.08 $\pm$ 0.09	0.01 $\pm$ 0.02	0.01 $\pm$ 0.02
SEE		0.40	0.29	0.29

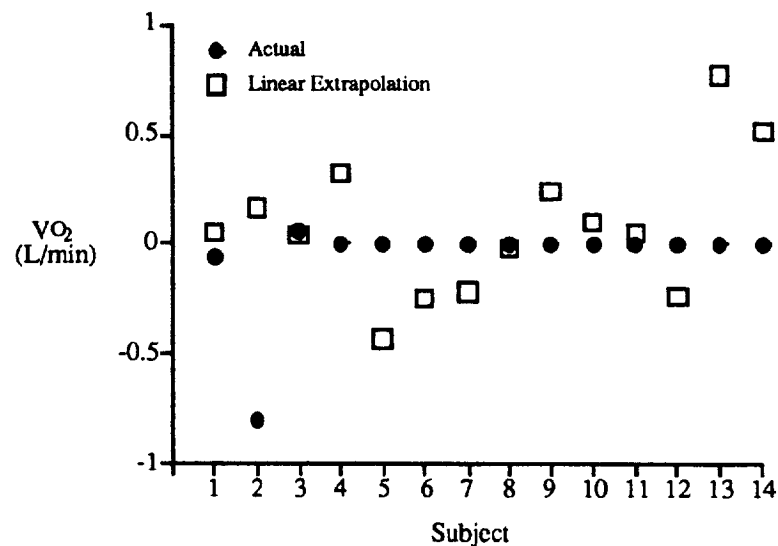
The differences between actual and predicted  $\dot{V}O_{2\max}$  values were computed. A repeated measures ANOVA was used to test for significant differences between the actual differences between tests in  $\dot{V}O_{2\max}$  and each of the prediction methods. The standard error of the estimate (SEE) for the change in  $\dot{V}O_{2\max}$  was computed for each prediction method.

## RESULTS

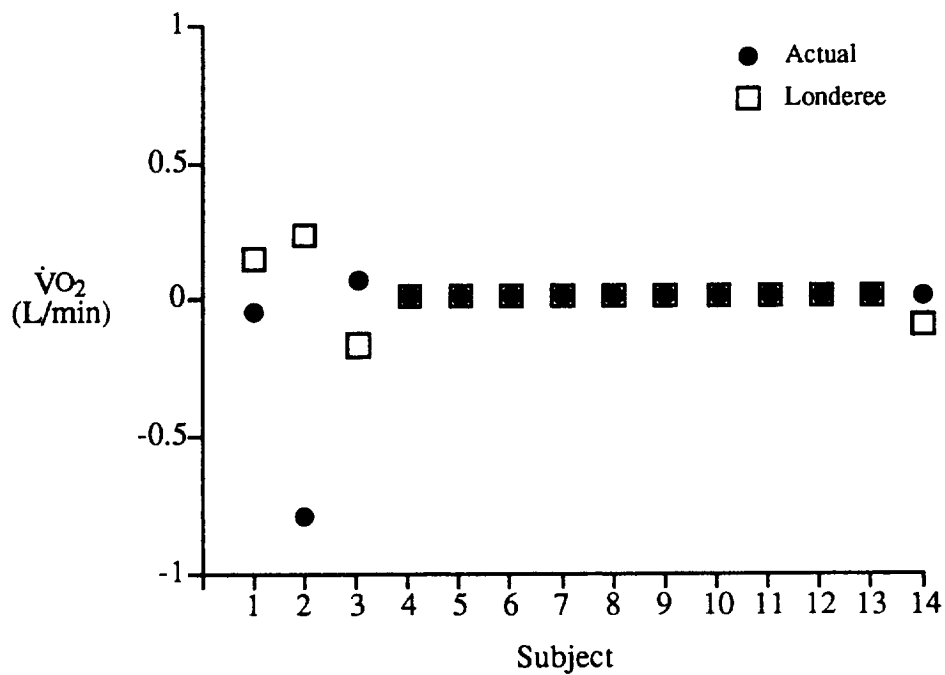
There was no significant difference between the actual and predicted MHR and  $\dot{V}O_{2\max}$  and there was no significant difference in actual MHR and  $\dot{V}O_{2\max}$  between the two tests. No significant difference ( $p>0.50$ ) was found between the actual difference between the two tests in  $\dot{V}O_{2\max}$  and any of the prediction methods. However, the linear extrapolation method using either of the MHR predictions resulted in the highest standard error. Comparisons among the actual change in  $\dot{V}O_{2\max}$  and each of the prediction methods for individuals are displayed in Figures 3 through 8.



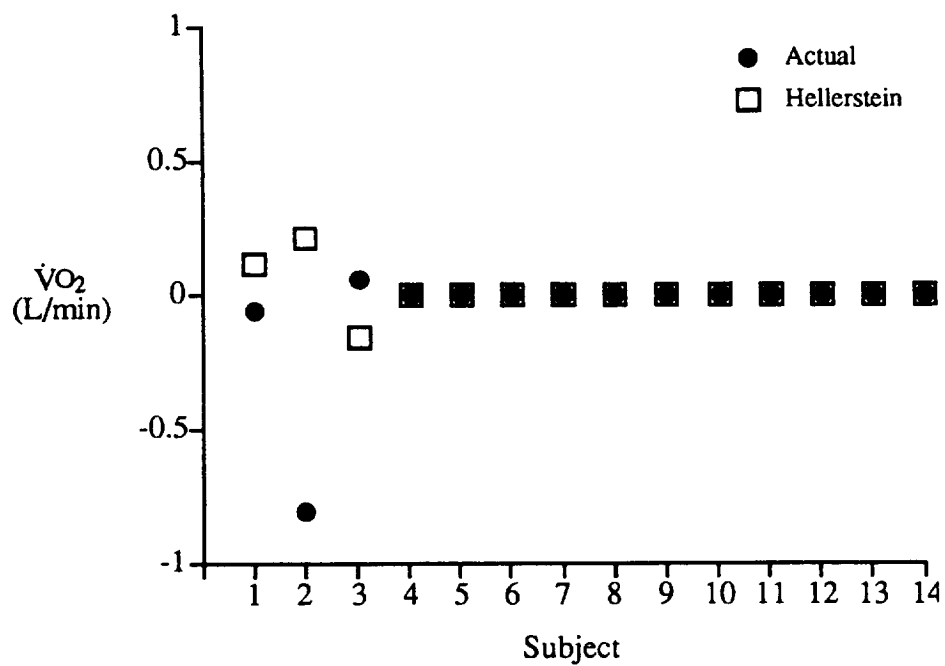
**Figure 3.** Actual  $\dot{V}O_2$  difference vs. Hellerstein prediction ( $MHR=205 \cdot [0.5 \cdot age]$ )



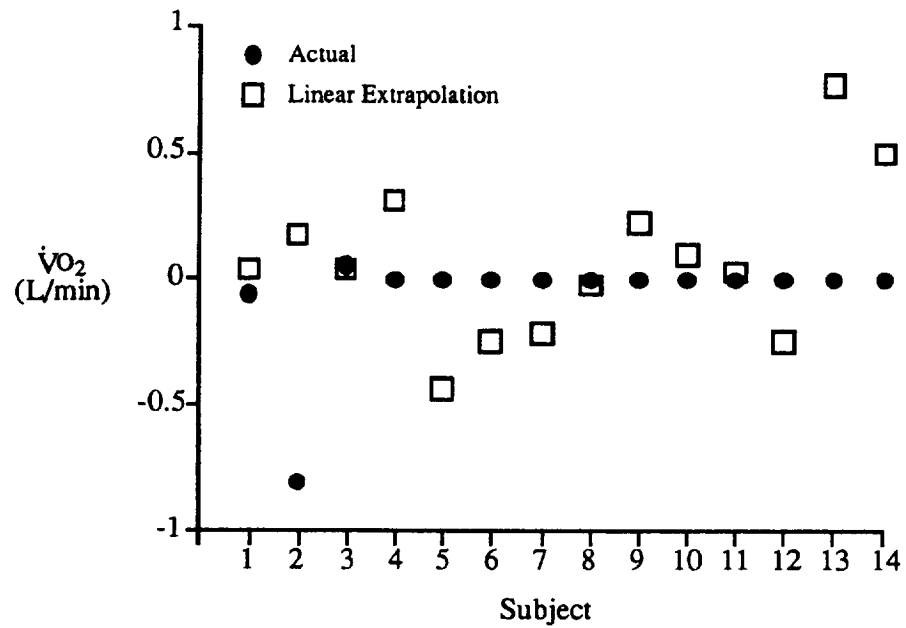
**Figure 4.** Actual  $\dot{V}O_2$  difference vs. linear extrapolation prediction ( $MHR=205 \cdot [0.5 \cdot age]$ )



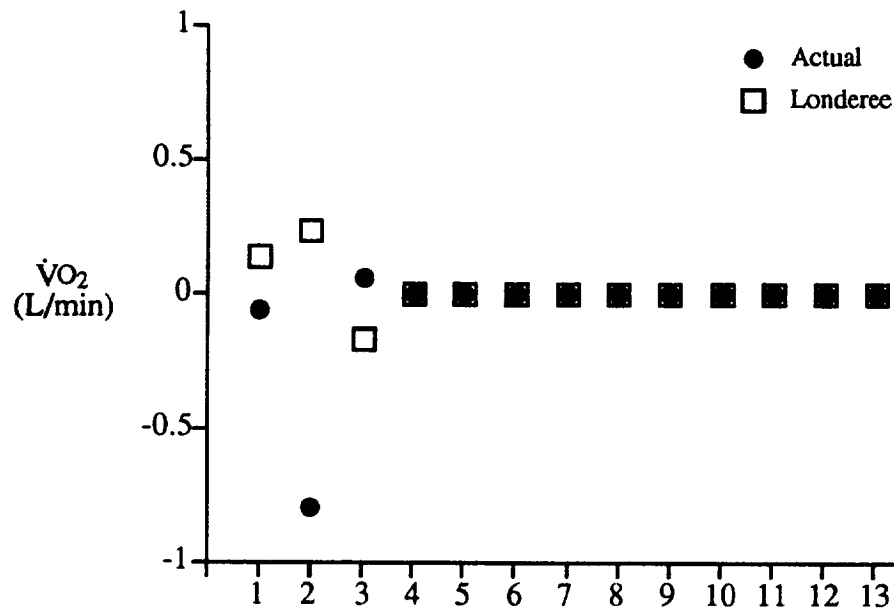
**Figure 5.** Actual  $\dot{V}O_2$  difference vs. Londeree prediction ( $MHR=205-\{0.5 \cdot age\}$ )



**Figure 6.** Actual  $\dot{V}O_2$  difference vs. Hellerstein prediction ( $MHR=200-age$ )



**Figure 7.** Actual  $\dot{V}O_2$  difference vs. linear extrapolation prediction ( $MHR=220-age$ )



**Figure 8.** Actual  $\dot{V}O_2$  difference vs. Londeree prediction ( $MHR=220-age$ )

## DISCUSSION

The results of this investigation suggest that it is irrelevant as to which  $\dot{V}O_{2\max}$  prediction method is employed when examining group data. However, members of the Astronaut Corps are interested primarily in their own individual results and how changes in their aerobic capacity after space flight will affect their personal performance. Therefore, an examination of how each prediction equation accurately tracks true changes in  $\dot{V}O_{2\max}$  for an individual is of greater importance in this situation than how the predictions assess the group.

Of the six different combinations of prediction methods employed in this investigation, the linear extrapolation method predicted a greater change in  $\dot{V}O_{2\max}$  for individuals than actually occurred, causing a higher standard error (SEE=0.40) than the other methods (SEE=0.28 to 0.29). It seems, therefore, that the linear extrapolation method is not a desirable prediction method when the change in  $\dot{V}O_{2\max}$  is expected to be small. The variability of this method could result in a predicted change in  $\dot{V}O_{2\max}$  for an individual even though none had actually occurred and, therefore, yield erroneous conclusions. An examination of the Figures 3 through 8 exemplifies how individual predictions and their changes can be masked by only observing group mean data. Similarities between the graphs of the results of the single-point methods can be attributed to the similarities between the equations.

However, this investigation primarily assesses the ability of the prediction methods to accurately determine  $\dot{V}O_{2\max}$  changes when the difference in measured  $\dot{V}O_{2\max}$  is not significant. Investigations regarding the Astronaut Corps after space flight have reported decrements of 10 percent [10]. To determine if these prediction methods can accurately assess these larger changes in aerobic capacity, future research should focus on the sensitivity of  $\dot{V}O_{2\max}$  prediction methods to detect greater differences in  $\dot{V}O_{2\max}$ . Also, at this time it is unclear whether these prediction methods can be accurately used during or after space flight as the HR- $\dot{V}O_{2\max}$  relationship may be altered during these conditions.

A criticism of this investigation might be that we actually assessed the variability of the equations to determine  $\dot{V}O_{2\text{peak}}$  rather than  $\dot{V}O_{2\max}$ . It is true that most of the subjects did not display a plateau of  $\dot{V}O_2$  normally associated with the attainment of  $\dot{V}O_{2\max}$  during the test because this protocol was not designed to elicit such a response. However, all subjects in all tests were highly motivated, experienced test subjects, and each displayed at least two of the three physiologic responses normally associated with a maximal effort (i.e., attainment of predicted MHR and a respiratory exchange ratio greater than 1.1 [6, 9]).

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